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# Teaching energy: thoughts from the SPT11–14 project

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**Abstract**

Describing the world in terms of energy is necessarily quantitative: one must be able to do the sums for the description to gain a purchase. Whilst teaching younger children (say 11–14 years old) the full quantitative description is not available and this has made the introductory teaching of energy a contentious area. By focusing on representations of energy that respect this quantitative essence, without demanding that calculations are actually done, one can develop a manipulable model of the abstract idea of energy to be shared with children that is much more plausible, intelligible and fruitful than one based solely on a verbal description. Here I argue this case, indicating the ways in which such a model may be useful.

## The challenge

There have been some professional differences about the teaching of energy over the years (Duit 1987, Ellse 1988, Warren 1991). Introductory accounts designed for the early years of secondary education produce particularly sharp disagreements. However many of the approaches discussed suffer from what I consider to be a fatal defect: children (and perhaps also their teachers) do not have a sound model to think with. If the idea of energy is to be plausible, fruitful and intelligible, so becoming a useful tool for children to think with, then its core must be a way of thinking; that is a useful description of situations for a particular purpose: a manipulable model. They must know what the idea can be used for, and how. If the what and the how of the idea-in-use are not introduced and practised, then I think that one is not seriously engaged with science, as a culturally significant explanatory schema.

I think that progress can be made by balancing respect for the calculated and conserved nature of the quantity ‘energy’ with the capabilities of children in the target range. So one will be unable to require that the calculations be performed. However that should not be seen as restricting descriptions to words only. This revisits the word wars, the upshot of which is series of prohibitions for teachers, leaving them in a state where they are somewhat unsure of what they should say, but knowing only too well the penalties for deviating from the prescribed vocabulary. What is needed, I believe, is a liberating description, that enables teachers to work out for themselves a sensible way forward in particular classroom situations. So teachers also need to have a model for thinking about energy, that is evocative and suggestive, without having to perform calculations. Busy teachers need an understanding of energy expressed using building blocks that they will use to construct an understanding for children. Therefore the teacher’s reasoning should not be too many steps removed from the way in which the material will

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be represented for the children. One suitable starting place is to consider how children might be thinking about energy when facing a rather traditional examination question as a 16-year-old. I think one can see what could do with improving in the current approaches to the teaching of energy by imagining what might be going on in children's heads as they try to work out an answer to such questions. What is their depiction of energy: how are they thinking about this calculated, conserved, quantity? One might then compare this situation with those likely to hold when considering a question about electricity or force and motion. One wants the children to tackle the questions with confidence, rather than just following an algorithm, or guessing. So one might hope to share a model of thinking about energy that is useful to these children.

One apparently under-exploited solution is to consider non-numerical and non-verbal depictions of energy (with the notable exception of the energy and change materials (Boohan and Ogborn 1995)) that are not words: so a shared way of talking about energy that respects the constraints outlined above.

## Using the idea for real

In order to consider how one might ask children to think about energy; start by assembling a model of how the professionals use the idea. That is, focus on the use of the idea: seeing this use as a tool, useful as a means of describing the world for particular purposes. First off, energy is never used to predict what will happen: it is, in that memorable phrase 'not the go of things' (Boohan and Ogborn 1995). Instead, somewhat ironically in the light of the introduction, it is used to find out what cannot happen. It is the ultimate limiting factor. Professionals imagine a possible process, trying, often not with complete success, to find where there are changes in energy associated with particular physical changes. Then they compare the calculated energies as this process evolves, so finding out whether the process is possible.

Energy may be a unifying concept, but to actually track down changes in energy, professionals need to consider facets of any process, not the process in its entirety. This is a simple consequence of an ability to calculate only changes in energy. Only by paying attention to particular changes can the energy be tracked. In each case where we are able to calculate a change in energy the possibility of this calculation depends on the identification of physical changes as a process occurs. Quantifying these changes gets one started on the road to calculating energy changes. Without a knowledge of the change in such quantities, and so a precise account of the physical process, an energy description can get no purchase on the world. So one needs physical processes to have been well described in order to be certain that the calculations that we perform have some connections with what is happening and so some meaning. In particular one needs to specify the process to study fully, from the initial snapshot to the final snapshot.

## Developing an approach

Working with energy should be distinguished from working with power to keep them distinct; here I will develop a description that follows the practice described in the paragraphs above of moving from one snapshot to another. Later I will return to deal with flows of energy, and so power. The idea of energy is useful only to the extent that we can perform the calculations enabled by considering different facets of the processes. Some purchase on a process is enabled by these calculations. The result of these calculations is that one has pinned down a quantity of energy. So start with that small success: a store of energy has been identified. If one has used a mass being lifted as the calculating mechanism, then it seems simple to call this a gravitational (or, far more simply but less elegantly, a gravity) store of energy. This store can be more or less full, being emptied or filled, by the simple action of stretching or relaxing the gravitational spring.

Similar thinking leads to a small collection of stores: thought of as places where one can pin down quantities of energy by calculation. Seeing that some processes are associated with chemical changes, as reactants combine to give products, leads somewhat naturally to considering how the chemical store of energy might be augmented or depleted. Similar changes extracted from the physical description lead to the identification of a number of stores. In each case these are classifications to suit our purposes. We can only pin energy down where we can calculate a change in the quantity in a store, so we need to find energy whilst it is located in stores. With other perceptual

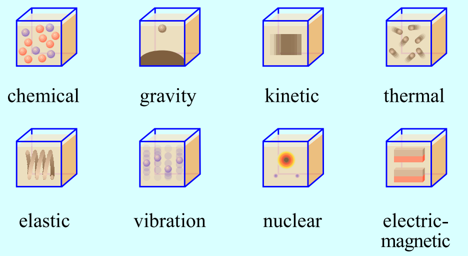


**Figure 1.** Representations of stores of energy.

apparatus we might be able to see the energy in other ways: for now, we are stuck with this approach. Although physicists think that energy is conserved and that it is the same energy that appears in one store when another is emptied, this has to be painstakingly checked by calculating the energy in all the stores—there is no shortcut.

Here then is a classification of the places in which one might look to pin down the energy (see figure 1). In each case one can only calculate the change in energy in the store, and one needs to look for clues in the physical description in seeking to pin down the energy.

Store of energy—energy stored changes when:

- Gravity: an object alters its height above a planet.
- Kinetic: an object speeds up or slows down.
- Thermal: an object warms up or cools down.
- Elastic: an object is stretched or squeezed.
- Chemical: reactants combine or separate to give products.
- Vibration: a mechanical wave has its amplitude increased or decreased.
- Electric–magnetic: magnets or electric charges are pulled apart or allowed to come closer together.
- Nuclear: nuclear particles are rearranged, for example in fission or fusion.

These are probably not the only eight stores that one could argue for. Yet they are consistent and form a useful categorization for the purposes of teaching. Apart from the school laboratory based work in the conservation of energy, an eye has been kept on issues of depletion and renewal of natural resources in constructing this list, so giving a connection to discussions of power demand and supply.

Beginning to develop a classroom description of energy consists of correctly applying these stores to situations (figure 2), so effectively issuing promissory notes for the calculations that will be done in the fully quantified description, somewhat later. Yet this promise of quantification, however conditional, is central. If one cannot do the calculations then there is no point in developing energetic descriptions, as it is only through quantification that an energetic description has any use: it will limit possibilities by telling you what may not happen. Correctly identifying stores, thinking about how much of the energy that leaves one store enters the other identified stores and so thinking about conservation, efficiency and dissipation may be enough to start off with. That thinking with stores can guide discussion quite naturally into these three areas is enough for the approach to have considerable merit.

So an appropriate description comes out of a careful analysis of this schematic account of the use of the idea of energy. First identify the process that one wishes to describe, including well defined start and end points. Then use the description as a starting point to look for calculable energy changes. Summarize these changes to see what is and is not possible, or perhaps find that your description is not as complete as you had hoped, in that some energy has not been accounted for. To promote this hunt for the energy as the process unfolds, seek a depiction that is essentially quantitative in order to provide a continuous reminder that one should always look for where the energy has gone and how much has been shifted. Essential to this depiction is that in tracking energy one relies on snapshots, with energy being shifted as a result of the processes occurring between snapshots. So calculations performed at these different times reveal different quantities of energy. Nevertheless one hopes to find that the total is unchanged. Energy cannot be located with a magnifying glass: it is a calculated quantity, not something directly inspectable. But it is conserved quantity, and one is very tempted to think of it moving about as it shifts from being captured by one calculation to being identified by another. It is not, I think, helpful to locate energy in objects, as in a significant number of cases the energy is calculated by considering the interaction between objects (e.g. two separated masses, two reactants combined to form a product). A solution

Matching the types of power station to the energy stores depleted by that power station.

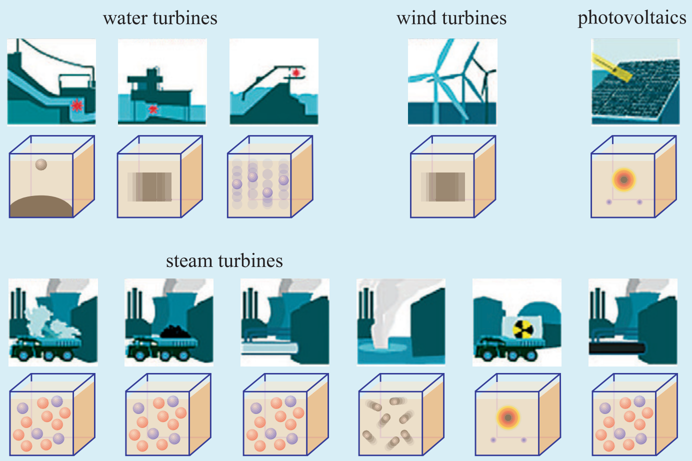


**Figure 2.** Connecting stores to resources.

is to insist on a quite separate level of description, that exploits these natural tendencies, so giving a simple and accessible depiction, that can, I think, prove fruitful. Depictions of energy for this age group are then freed from accusations of conflating different categories of entities. The trick has been pulled before, perhaps most famously by Feynman in his story about the children's blocks (Feynman 1963), vol. 1: lecture 4, section 1).

## Classroom implications for now

For current classroom practice, this analysis has a few straightforward implications:

(1) One needs to be very careful to describe the physical processes rather carefully, and to choose the process wisely, before trying to develop a description in terms of energy.

It is not useful to develop an energy description for all processes; one might be able to do so; but the point is to develop a description that gives you insight, not simply to do so for the sake of completeness. In particular one should respect the constraint that such descriptions will depend on calculations and that these calculations will indicate whether the process is possible or not. This emphasizes the role of energy as the ultimate limiting factor.

(2) One needs to select a pair of snapshots, one for the start of the process and one for the end of the process.

Many processes can be considered at different points in their evolution, with rather different outcomes for the extent to which the energy stores are augmented or depleted, or even the selection of stores.

(3) One needs to have a selection of stores, or other place-holding descriptions, that stand in place of the calculations that students who have studied further will be able to do. One might hope that these calculations will not be too far in the future for students who continue to study the sciences at school, and this, together with an analysis of the reasons for which one might want to do calculations, provides a rationale for selecting these eight stores. It seems rather important that however one chooses these depictions, they should ease children into the essential unity of energy and discussions of efficiency, dissipation, renewal of resources and conservation. In this respect I think one should be wary of discussion of forms and types of energy, as these lead children down the wrong path, I believe. It is probably best to have no adjectives directly qualifying the noun energy.

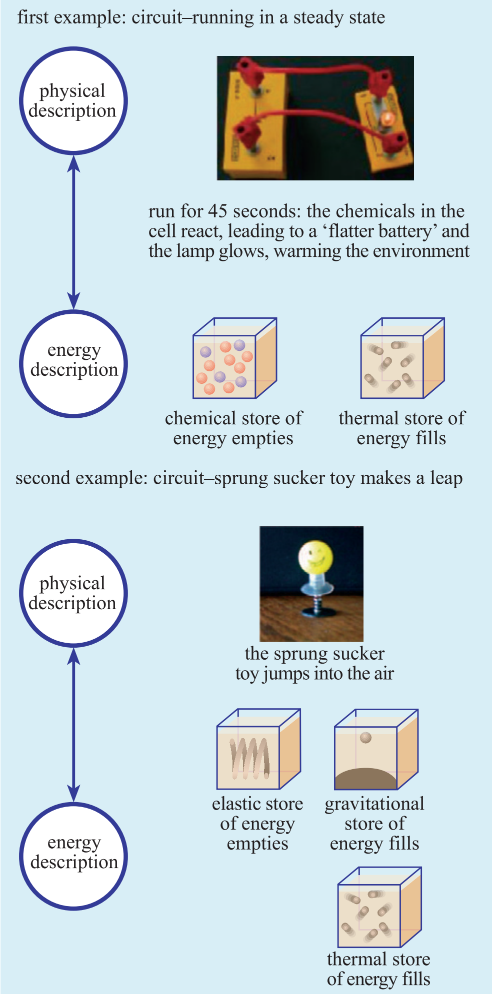


**Figure 3.** Simple descriptions using only stores.

(4) One should clearly separate the energy description, with its austere simplicity, from the physical mechanisms that effect the changes that determine where one has to look in order to pin the energy down. Descriptions in terms of energy make predictions only by prohibiting and permitting: they do not give causal mechanisms that tell what will happen next (figure 3).

## Challenging one's current practice

The major challenge to current practice is that one needs to sharpen up their thinking about the learning outcomes for topics deeply rooted in energy. Often, in England, the pragmatic aims are simply the ability to correctly complete the national curriculum test or GCSE questions, with children stumbling their way through inserting the correct labels without much idea of what they are labelling, or trying to combine numbers in such a way that the resultant seems simple enough to be correct. I think that we can do better, allowing children and their teachers to be more confident, by working with an underlying model. The approach needs to be rather thoroughgoing, and to involve the whole approach within science, and perhaps also geography, so that one has in mind a very clear idea of what is being communicated at any one instant. The approach outlined above is clear and consistent, tried in classrooms and developed in various in-service training events. It will involve some changes: say particularly with our tendency to label situations as containing large numbers of different types of energy. In the school laboratory in which I am currently writing there is a pupil-generated poster stating boldly that there are 14 types of energy: kinetic; gravitational potential; chemical; sound; light; heat; nuclear; elastic potential; infrared; electrical (other pupils in the class do not agree!). Perhaps this list is not exhaustive, or does not agree with your own departmental practice, but there are two on the list which do not appear as stores in the account developed here and which are on many such lists. We might therefore focus on these two, light and electrical, to see why thinking about these as being the same category of entities as the eight that we have listed above is unhelpful. It will emerge that there is a way in which they can be more helpfully thought of.

One might consider a simple circuit, and an account of what is happening in the circuit.

The following kind of description is quite common: 'chemical energy is converted to electrical energy which is then converted to heat and light energy'. In considering the interpretation of this description, and what might be understood by the labels, one should consider the calculations that might be done (always a good first step in planning for teaching about energy, because of its essentially quantitative nature) and also what is important about the electrical circuit. It seems, after a few moments' reflection, that the electrical circuit is not functioning as a repository or store of energy in the same way that a moving mass or

**Figure 4.** A simple circuit.

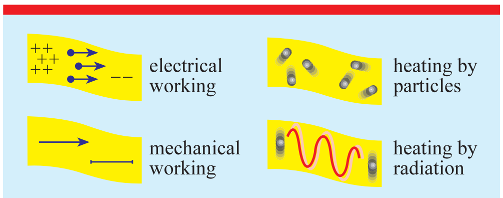


**Figure 5.** Four pathways to describe flows of energy, either depleting or augmenting the content of stores.

lifted mass might be, for example. One cannot deplete it in order to do a useful job in the same way as one can slow down one mass, or allow another to fall. In fact the electrical link depicted in figure 4 is shifting energy; it is active in emptying one store and also in filling another. In thinking about the link one naturally thinks about a rate: a flow. When there is a flow, then one can calculate the flow. After the flow has finished, there is nothing remaining to be calculated. One can, of course, calculate what has happened: indeed one calculates how much energy has been shifted from one store and, how much energy has been shifted to another store (by multiplying a rate by a time). That is, one calculates the energy that has shifted along a pathway.

So electric circuits provide a pathway: electrical working. The natural units are watts. It is about a flow, not a store. Lighting is like this also. It too is about a flow, now of the number of photons arriving or departing per second. We measure only the rate of arrival or departure (after all, the most comprehensive model of light that we have suggests that we really do not have any idea what happens between departure and arrival). Heating may also be thought of as a pathway with a rate, either due to the arrival or departure of photons at longer wavelengths, or down to the atoms doing their bit by convection or by conduction. So it makes sense to identify two more pathways: heating by radiation and heating by molecules. Finally, by a somewhat roundabout route we arrive at mechanical working as the final identified pathway, although it might be the first one to be met, particularly if one follows a more traditional view of the teaching of energy. Here the rate of working is found by multiplying the force by the speed, perhaps first met by children, albeit somewhat intuitively, in the rope model of electric circuits (also used in the SPT11-14 materials).

So one challenge is to distinguish clearly between stores and pathways—essentially between energy and power (for a complete set see figure 5). Energy is conserved; power is not. One needs to keep these quantitative thoughts in mind whilst developing qualitative descriptions for use early on in children's learning about energy (figures 6 and 7).

## Developments for the future

One starting point for this approach is that one ought to have clear building blocks from which to construct an explanation. Versions of these blocks are what the children reconstruct: the concepts which underpin the explanatory story. However to think of these as building blocks is much more fruitful, I believe, simply because we are then encouraged to think of them as something almost tangible, but with a function that only makes sense when we see how it fits into a whole. This near-tangibility appears to give children a manipulable model: something to think with. That energy becomes an idea that children are able to reason with, to use with increasing precision in order to describe situations is what allows those children to appreciate the power of the idea and see that it is a plausible, fruitful and intelligible way of describing the world (Osborne and Freyberg 1985, p 41). In building up towards this state one is continually constructing explanations, refining the understanding of the ideas used in the explanations, by reshaping the blocks. Eventually one ends up with dressed stone blocks, that fit together to make a rather fine building. However, presenting these polished walls to beginners does not allow them to see how the building gets to

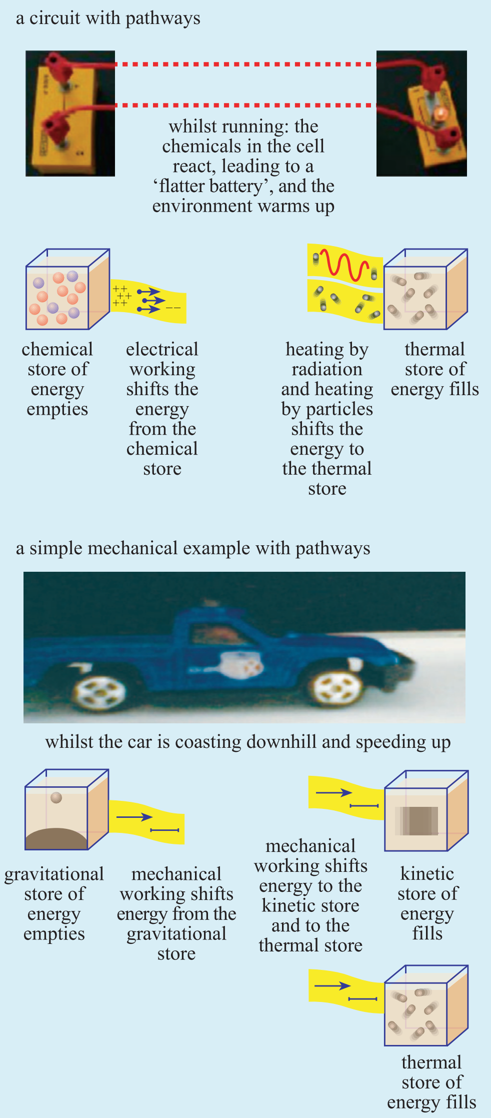


**Figure 6.** Stores and pathways.

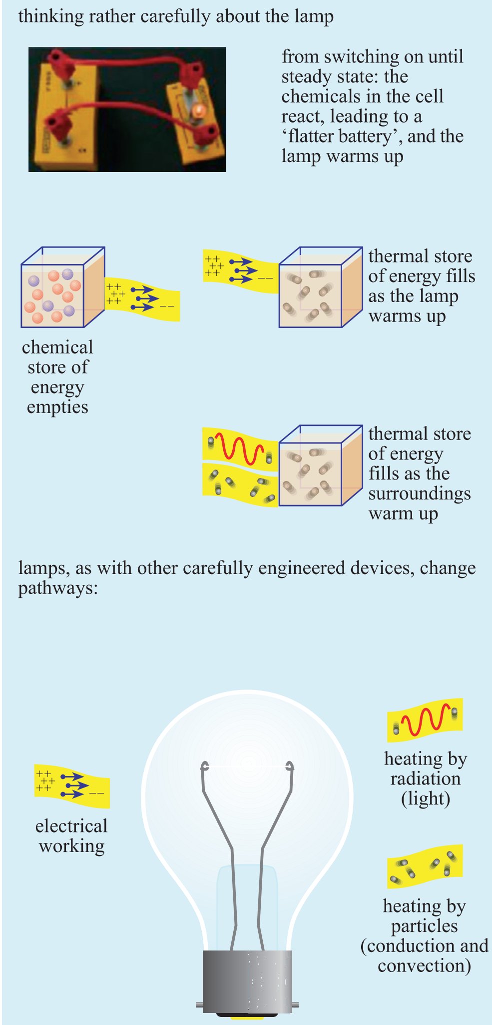


**Figure 7.** Light and electricity.

be constructed, or to reconstruct a building for themselves. And sheer polished walls can seem very intimidating to those who are faced with having to scale those walls. In considering a teaching approach I think one therefore ought to focus on establishing manipulable models, with quite concrete representations to depict the essence of how one wants children to think about an idea. In this way one is recognizing and exploiting the multi-model nature of communication (Kress *et al* 2001).

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